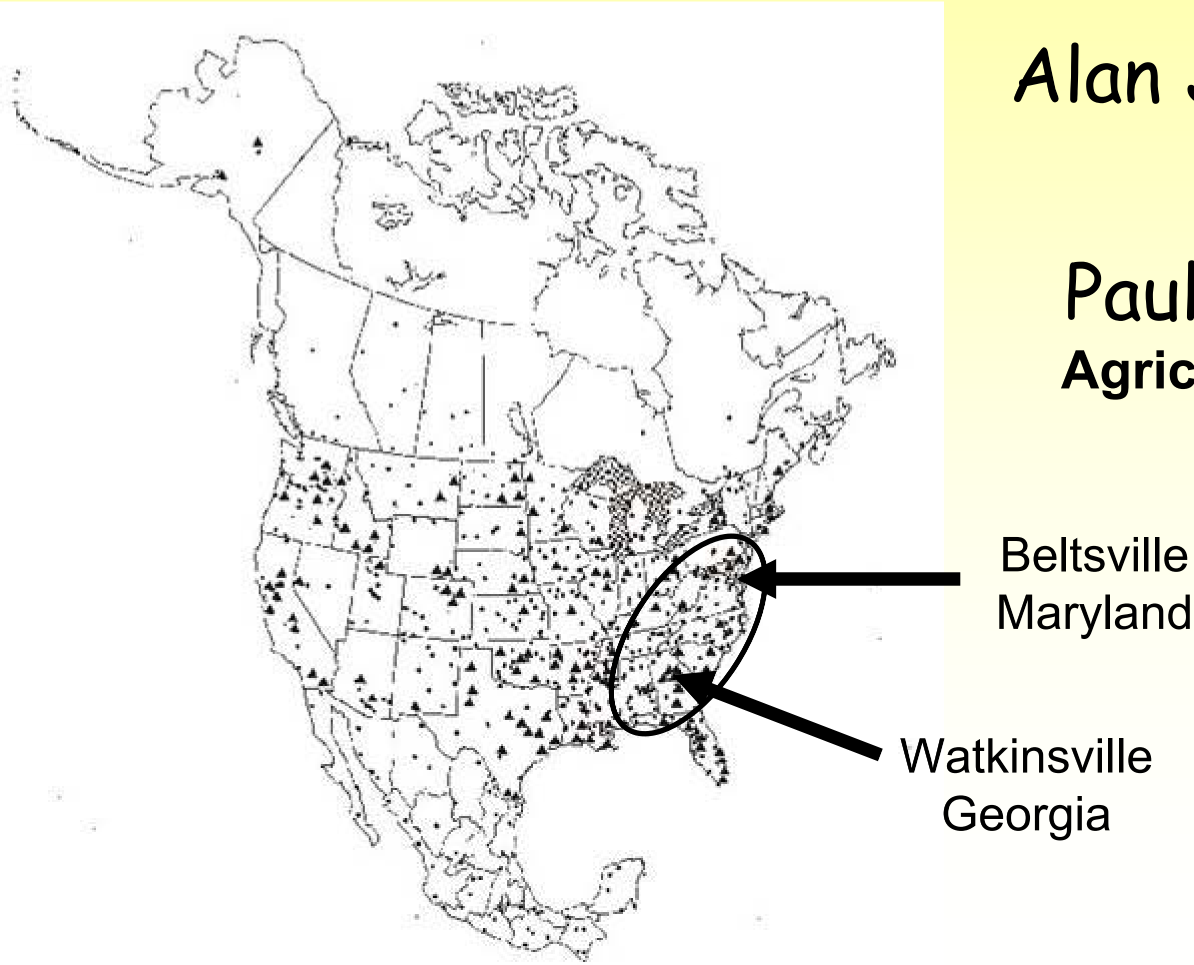
Carbon Sequestration and Land Degradation



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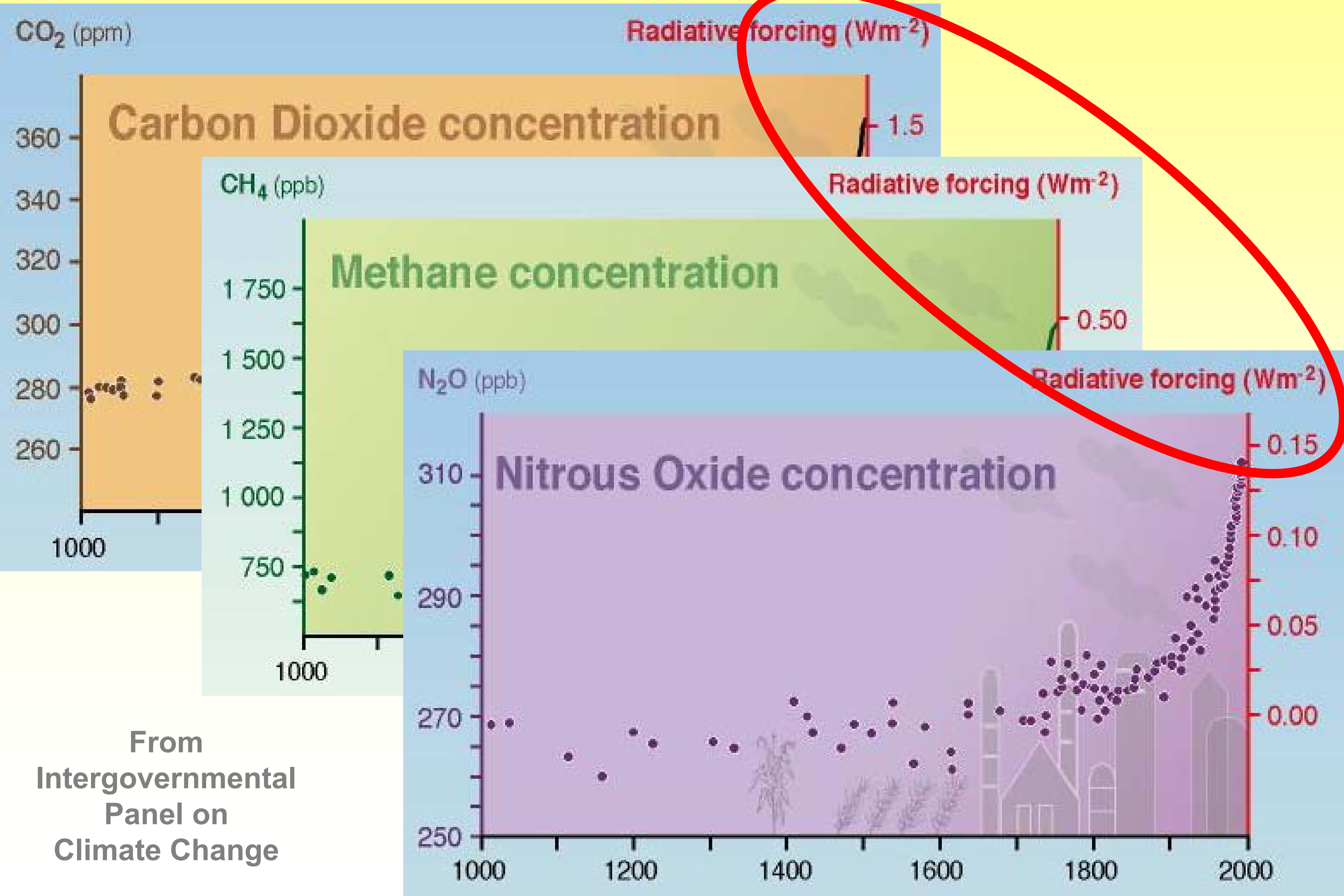
Presentation Outline

1. Carbon sequestration concepts and rationale
2. Relevant management approaches to avoid land degradation and foster carbon sequestration
3. Summary of research quantifying soil carbon sequestration

Global Concern is in the Air



From Intergovernmental Panel on Climate Change

Why are Greenhouse Gases Important?

1. Global ecological concern for the anthropogenic source of increasing concentration in the atmosphere since 1750 (Intergovernmental Panel on Climate Change, 2001):
   - ✓ CO_2 – 31% increase
   - ✓ CH_4 – 151% increase
   - ✓ N_2O – 17% increase
2. Cause radiative forcing of the atmosphere, which could alter global temperature and ecosystem functioning
3. Can be manipulated by human activities

Managing Carbon Emission

- ✓ Rising concentration of greenhouse gases has been largely attributed to expanding use of fossil fuels as an energy source, resulting in emission of CO_2 to the atmosphere
- ✓ Reducing net greenhouse gas emission is possible:
  1. Reduce fossil fuel combustion by becoming more energy efficient
  2. Rely more on low-carbon energy sources
     - Solar energy capture
     - Wind power generation
     - Biomass fuels
  3. Carbon sequestration

Carbon Sequestration

- ✓ Long-term storage of carbon in:
  1. Terrestrial biosphere
  2. Underground in geologic formations
  3. Oceans

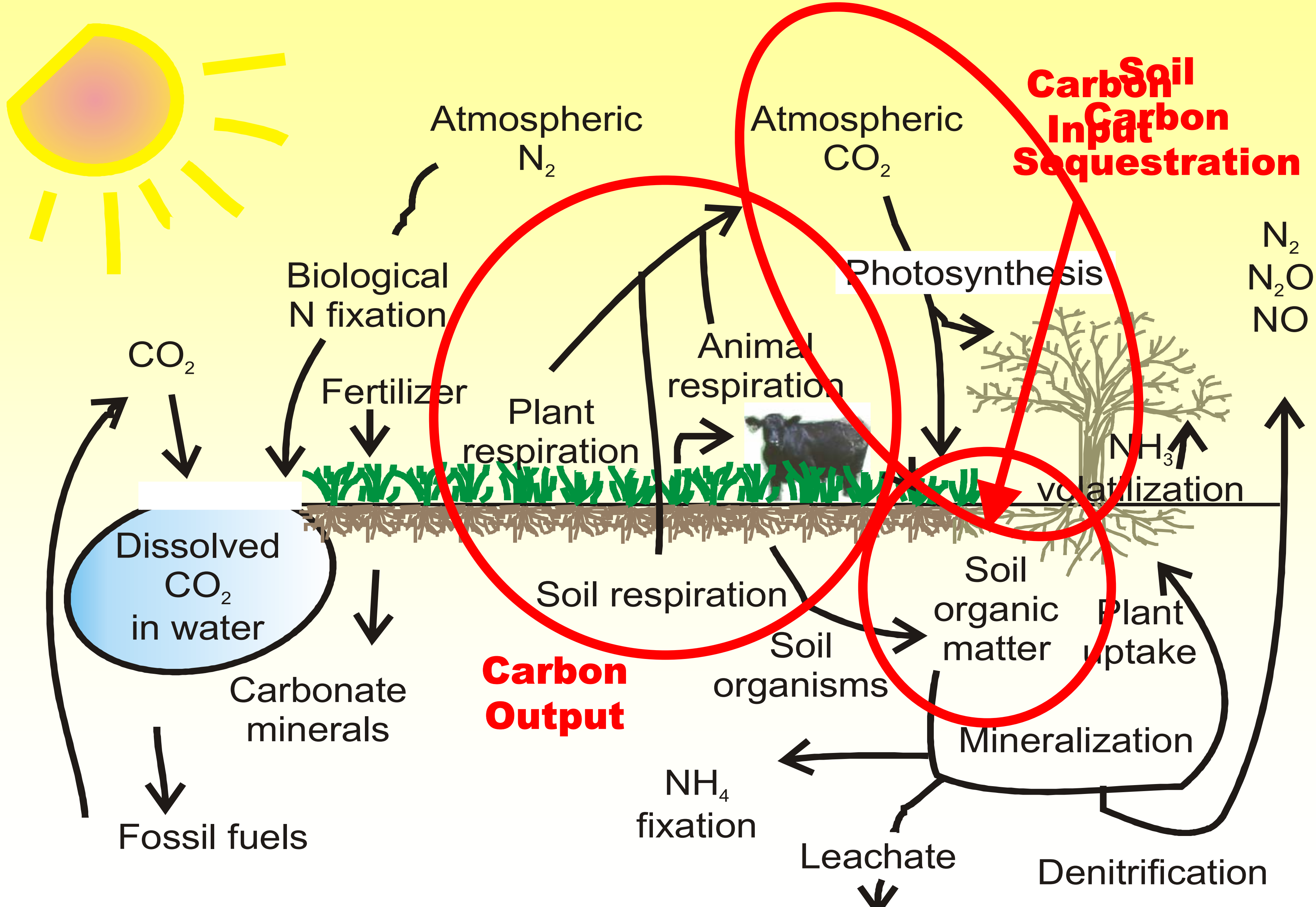
so that the buildup of CO_2 will reduce or slow

- ✓ May be accomplished by:
  1. Maintaining or enhancing natural processes
  2. Developing novel techniques to dispose of carbon

Terrestrial Carbon Sequestration

1. Increasing the net fixation of atmospheric CO_2 by terrestrial vegetation with emphasis on enhancing physiology and rate of photosynthesis of vascular plants
2. Retaining carbon in plant materials and enhancing the transformation of carbon to soil organic matter
3. Reducing the emission of CO_2 from soils caused by heterotrophic oxidation of soil organic carbon
4. Increasing the capacity of deserts and degraded lands to sequester carbon

Terrestrial Carbon Sequestration



Management Approaches to Sequester Carbon from Atmosphere to Biosphere

<u>Focus on maximizing carbon input</u>

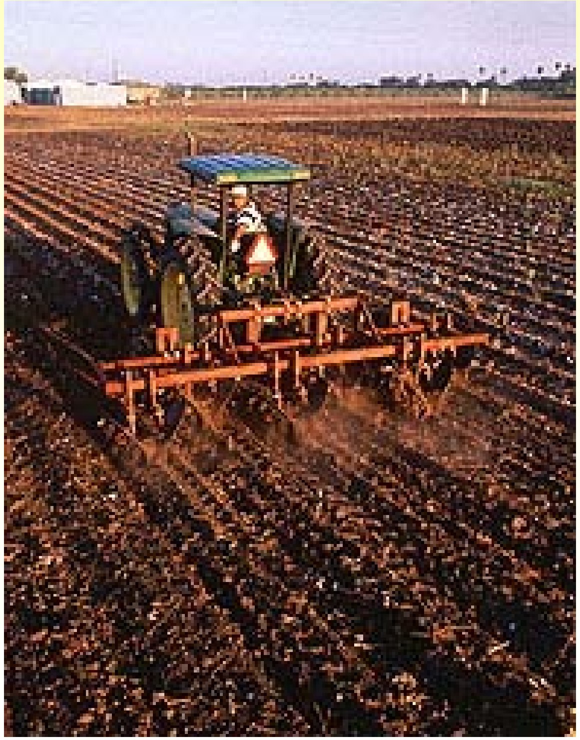
ARS Image Number K5141-4

- Plant selection
  - Species, cultivar, variety
  - Growth habit (perennial / annual)
  - Rotation sequence
  - Biomass energy crops
- Tillage
  - Type
  - Frequency
- Fertilization
  - Rate, timing, placement
  - Organic amendments
- Integrated management
  - Pest control
  - Crop / livestock systems

Management Approaches to Sequester Soil Carbon from Atmosphere to Biosphere

Focus on minimizing carbon loss from soil

- Reducing soil disturbance
  - Less intensive tillage
  - Controlling erosion
- Utilizing available soil water
  - Promotes optimum plant growth
  - Reduces soil microbial activity
- Maintaining surface residue cover
  - Increased plant water use and production
  - More fungal dominance in soil



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Management Practices to Sequester Carbon and Counter Land Degradation

- ✓ Tree plantings
- ✓ Conservation-tillage cropping
- ✓ Animal manure application
- ✓ Green-manure cropping systems
- ✓ Improved grassland management
- ✓ Cropland-grazingland rotations
- ✓ Optimal fertilization

ARS Image Number K5951-1

Tree Plantings

Tree plantings have the advantage of accumulating carbon in perennial biomass of above- and below-ground growth, as well as in soil organic matter.

www.amityfoundation.org/

Issues of importance are:

- Climate
- Selecting adapted species
- Soil condition
- Plant density
- Intended use
- Type of intercropping

www.amityfoundation.org/

Tree Plantings

Using CENTURY and RothC models in Sudan and Nigeria, soil organic C accumulation with tree plantings was estimated at 0.10 $\pm$ 0.05 Mg C/ha/yr (Farage et al., 2007, Soil Till. Res.)

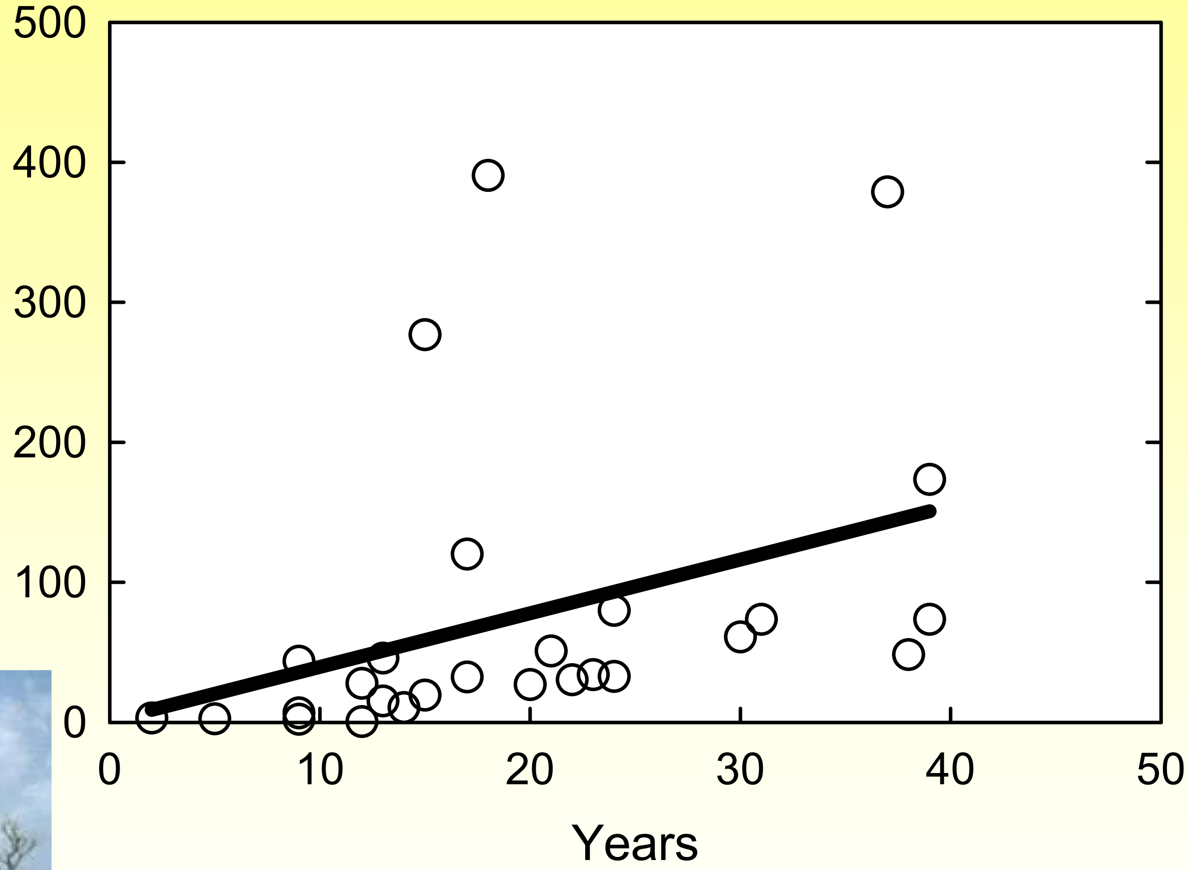


Photo by Mamadou Doumbia

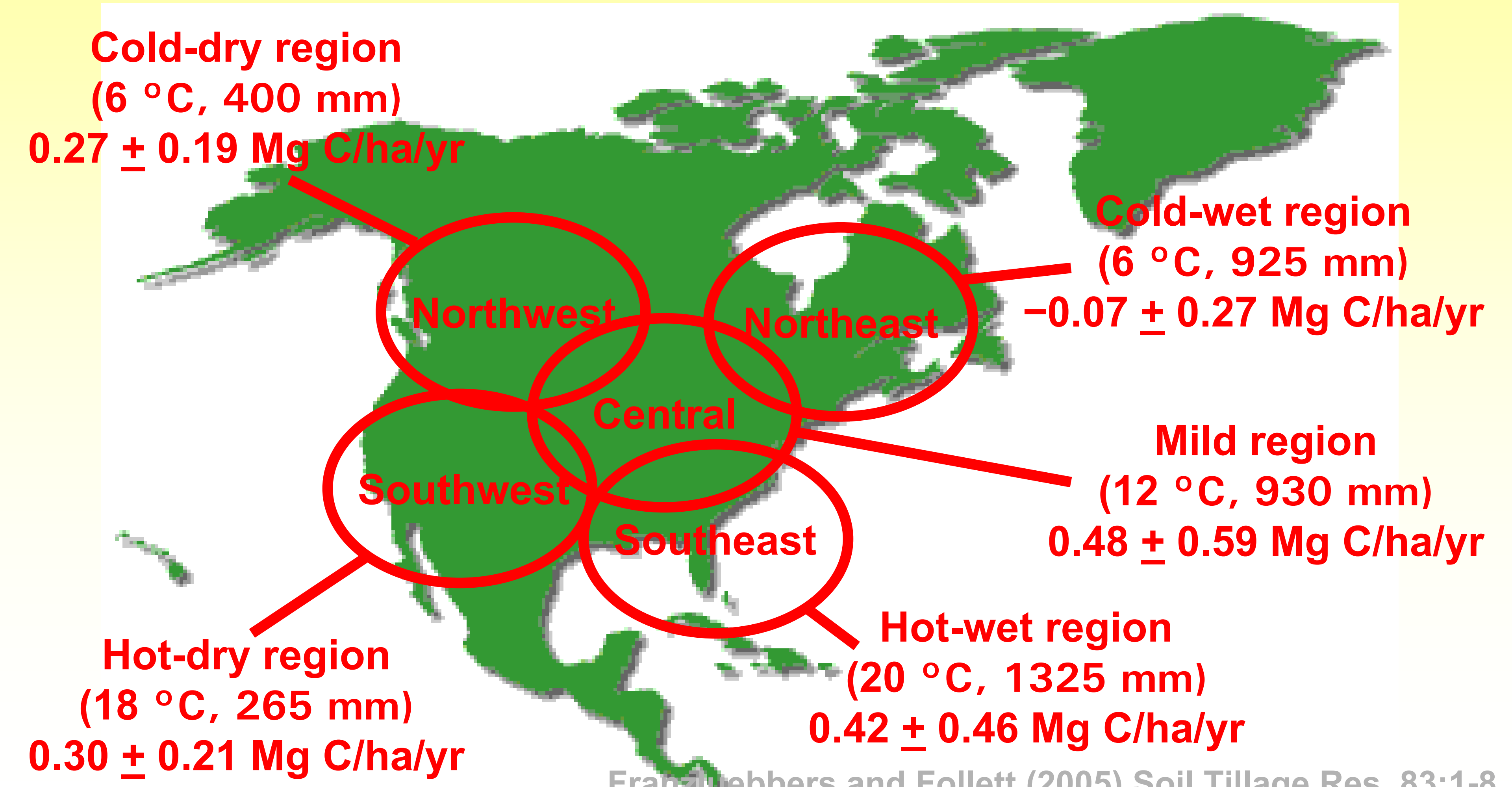
Data from Environment Australia (1998). Plantation survey data in 400-600 mm/yr zone. Mean carbon accumulation rate of 3.8 Mg C/ha/yr.

Conservation-Tillage Cropping

Minimal disturbance of the soil surface is critical in avoiding soil organic matter loss from erosion and microbial decomposition.

Conservation-Tillage Cropping

In the USA and Canada, no-tillage cropping can sequester an average of 0.33 Mg C/ha/yr.



Franzluebbers and Follett (2005) Soil Tillage Res. 83:1-8

Conservation-Tillage Cropping

No tillage needs high-residue producing cropping system to be effective.

Photos of 2 no-tillage systems in Virginia USA

Soil Organic Carbon Sequestration in the Southeastern USA

0.28 ± 0.44 Mg C/ha/yr (without cover cropping)

0.53 ± 0.45 Mg C/ha/yr (with cover cropping)

Franzluebbers (2005) Soil Tillage Res. 83:120-147.

Conservation-Tillage Cropping

From the 12th year of an irrigated wheat-maize rotation in the volcanic highlands of central Mexico, rate of water infiltration, crop yield, and soil organic C reflected differences in surface soil condition due to residue management:

			Yield ($Mg\ ha^{-1}$)	1996-2002
Tillage	**Residues**	**Infiltration ($cm\ h^{-1}$)**	**Maize**	**Wheat**
Zero	**Without**	**18**	**3.4**	**3.9**
Zero	**With**	**90**	**4.8**	**5.4**

Retaining residues for 12 years significantly increased soil organic C, but absolute treatment values were not reported.

Govaerts et al. (2006) Soil Tillage Res. (in press)

Conservation-Tillage Cropping

Using:

(a) remote sensing (Quickbird, SPOT) of land use from a 64 km^2 area in Mali (750 mm yr^{-1})

(b) EPIC-Century modeling of agroecosystem processes

erosion and soil organic C sequestration were predicted (25 y):

Management (49% cropped)	Erosion ($Mg\ ha^{-1}\ yr^{-1}$)	Soil Organic C ($Mg\ ha^{-1}\ yr^{-1}$)
Conventional tillage (CT)	16.5	−0.023
CT with increased fertilizer	15.0	−0.006
Ridge tillage (RT)	6.6	0.001
RT with increased fertilizer	5.9	0.027
RT with fertilizer and residues	3.5	0.086

Doraiswamy et al. (2006) Agricultural Systems (in press)

Animal Manure Application

Since animal manure contains 40-60% carbon, its application to land should promote soil organic C sequestration.

Effect of manure application	Soil Organic C ($Mg\ ha^{-1}$) Without	With
2-yr studies (n=6)	19.8 ± 8.9	19.6 ± 8.4
11 ± 8-yr studies (n=8)	30.6 ± 11.4	36.8 ± 10.6
SOC sequestration for all ($Mg\ ha^{-1}\ yr^{-1}$)	0.26 ± 2.15	
SOC sequestration for >2-yr studies	0.72 ± 0.67	

Conversion of C in poultry litter to soil organic C was 17 ± 15%.

Note: Manure application transfers C from one land to another.

Franzluebbers (2005) Soil Tillage Res. 83:120-147.

Animal Manure Application

Long-term studies on farmyard manure (FYM) application to soil clearly show its benefit to soil fertility, yield enhancement, and soil C storage:

Kapkiyai et al. (1999) Soil Biol. Biochem. 31:1773-1782
18-yr field experiment in Kenya (23 °C, 970 mm)

- **0.17 $\pm$ 0.07 Mg C ha^{-1} yr^{-1} with 10 Mg ha^{-1} yr^{-1} FYM compared to without FYM**
- **9 $\pm$ 3% of added C retained in soil**
- **Crop yield with FYM (5.3 Mg ha^{-1}) $>$ without FYM (3.3 Mg ha^{-1})**

Agbenin and Goladi (1997) Agric. Ecosyst. Environ. 63:17-24
45-yr field experiment in Nigeria (28 °C, 1070 mm)

- **0.21$\pm$ 0.01 Mg C ha^{-1} yr^{-1} with 5 Mg ha^{-1} yr^{-1} FYM compared to without FYM**
- **Total soil phosphorus increased with FYM (21 $\pm$ 12 kg ha^{-1} yr^{-1})**

Animal Manure Application

Manna et al. (2006) Soil Tillage Res. (in press)
30-yr field experiment at Ranchi, India (23 °C, 1450 mm)

- Soil organic C with FYM (3.9 g kg^{-1}) > without FYM (3.3 g kg^{-1})
- Total soil N with FYM (422 mg kg^{-1}) > without FYM (361 mg kg^{-1})
- Soybean and wheat yields not generally affected by FYM

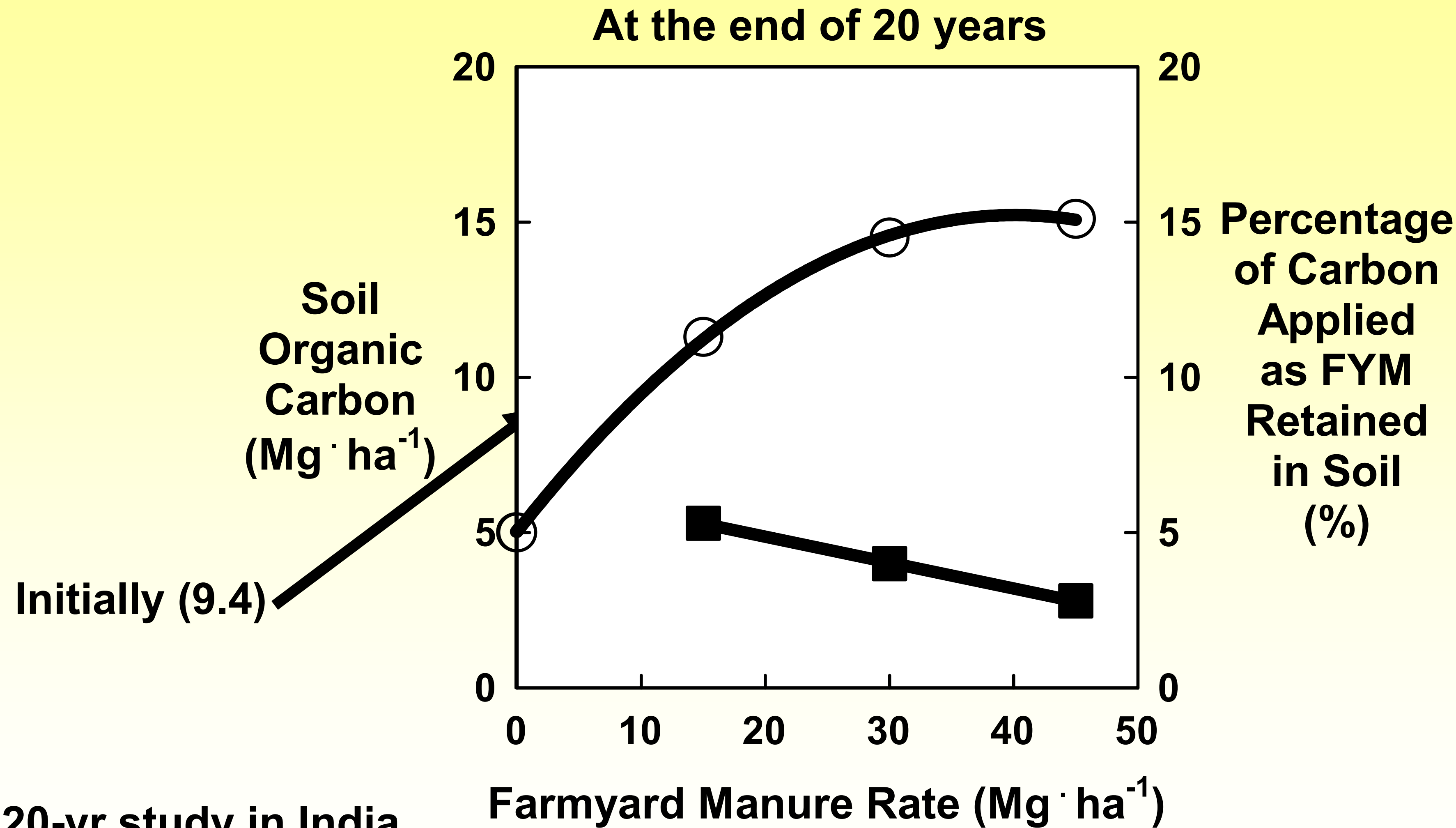
Kundu et al. (2006) Soil Tillage Res. (in press)
30-yr field experiment at Hawalbagh, India (1035 mm)

- 0.56 $\pm$ 0.02 Mg C ha^{-1} yr^{-1} with 10 Mg ha^{-1} yr^{-1} FYM compared to without FYM
- Above-ground yield with FYM (6.4 Mg ha^{-1}) > without FYM (2.7 Mg ha^{-1})

Govi et al. (1992) Soil Sci. 154:8-13
22-yr field experiment in Italy (14 °C, 760 mm)

- 0.20 Mg C ha^{-1} yr^{-1} with 7.5 Mg ha^{-1} yr^{-1} FYM compared to without FYM
- Soil humification index with FYM (60%) > without FYM (51%)

Animal Manure Application



20-yr study in India
(26 °C, 440 mm)
Pearl millet–wheat

Gupta et al. (1992) Arid Soil Res. Rehabil. 6:243-251

Animal Manure Application

Soil carbon retention rate from manure application is affected by climatic condition:

Percentage of carbon applied as manure retained in soil (review of literature in 2001)

Temperate or frigid regions (23 ± 15%)

Thermic regions (7 ± 5%)

Moist regions (8 ± 4%)

Dry regions (11 ± 14%)

Green-Manure Cropping Systems

On an abandoned brick-making site in southeastern China (16.5 °C, 1600 mm) [Zhang and Fang (2006) Soil Tillage Res. (in press)],

Planting of ryegrass (*Lolium perenne*) under China fir (*Cunninghamia lanceolata*) for 7 years resulted in soil organic C sequestration of 0.36 $\pm$ 0.40 Mg C ha^{-1} yr^{-1}.

With soybean as a green manure for 8 years in Columbia (27 °C, 2240 mm) (Basamba et al., 2006; Soil Tilllage Res. 91:131-142):

Response	Control	Green Manure
Maize yield (Mg ha^{-1})	3.5	4.2
Soil organic C (g kg^{-1})	24.9	23.8

www.agroecology.org/cases/greenmanure.htm

Green-Manure Cropping Systems

At the end of 12 years of Sesbania green manuring in India (24 °C, 715 mm) [Singh et al., 2006; Soil Tillage Res. (in press)],

Soil organic C sequestration was 0.09 $\pm$ 0.03 Mg C ha^{-1} yr^{-1}.

At the end of 13 years of wheat/soybean–maize cropping with and without vetch as a green-manure cover crop in southern Brazil (21 °C, 1740 mm) (Sisti et al., 2004; Soil Tilllage Res. 76:39-58):

Tillage system	Soil organic C Change (Mg ha^{-1} yr^{-1})
Conventional	−0.30 $\pm$ 0.15
Zero tillage	0.66 $\pm$ 0.26

Photo by Bob Bugg, www.ucdavis.edu

Improved Grassland Management

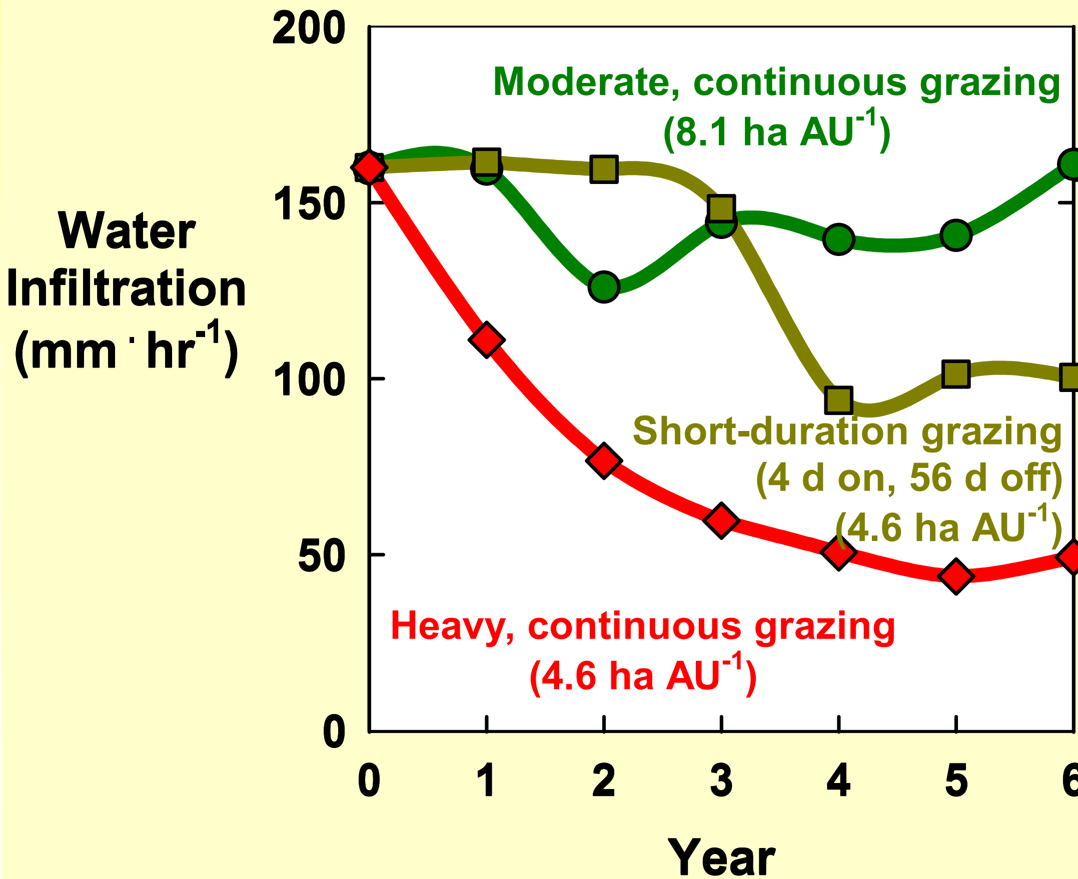
- Degradation of permanent grasslands can occur from accelerated soil erosion, compaction, drought, and salinization
- Strategies to sequester carbon in soil should improve quality of grasslands
- Strategies for restoration should include:
  - **Enhancing soil cover**
  - **Improving soil structure to minimize water runoff and soil erosion**

Improved Grassland Management

Achieving a balance between agricultural harvest and environmental protection is needed (i.e., stocking density should be optimized)

On an oak-grassland in central Texas (18 °C, 440 mm), water infiltration was highly related to percent ground cover

Management played a large role



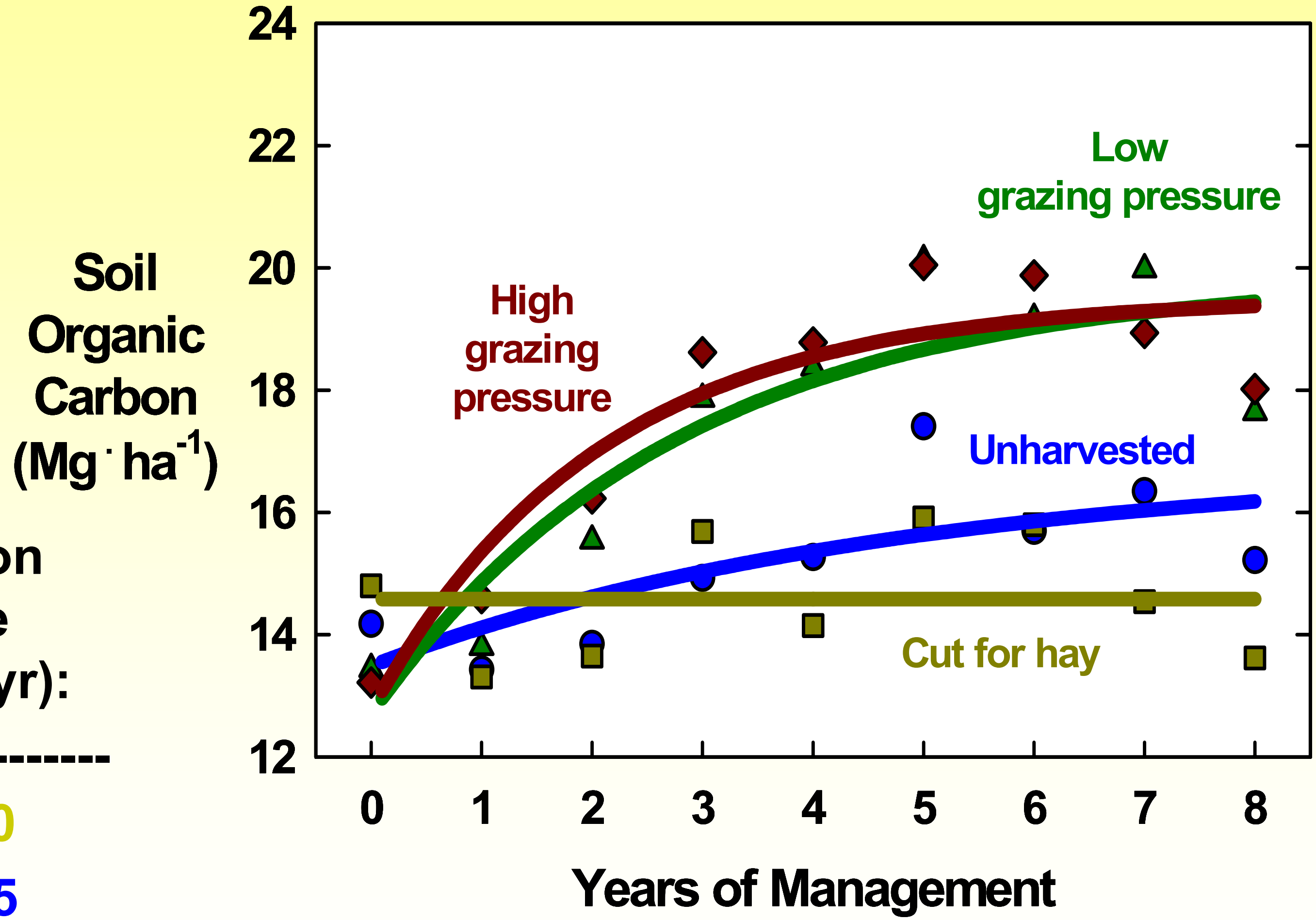
Thurow et al. (1988) J. Range Manage. 41:296-302

Improved Grassland Management

Establishment of bermudagrass pasture following long-term cropping in Georgia USA (16 °C, 1250 mm)

Soil organic carbon sequestration rate (Mg ha^{-1} yr^{-1}) (0-5 yr):

Hayed	0.30
Unharvested	0.65
Grazed	1.40

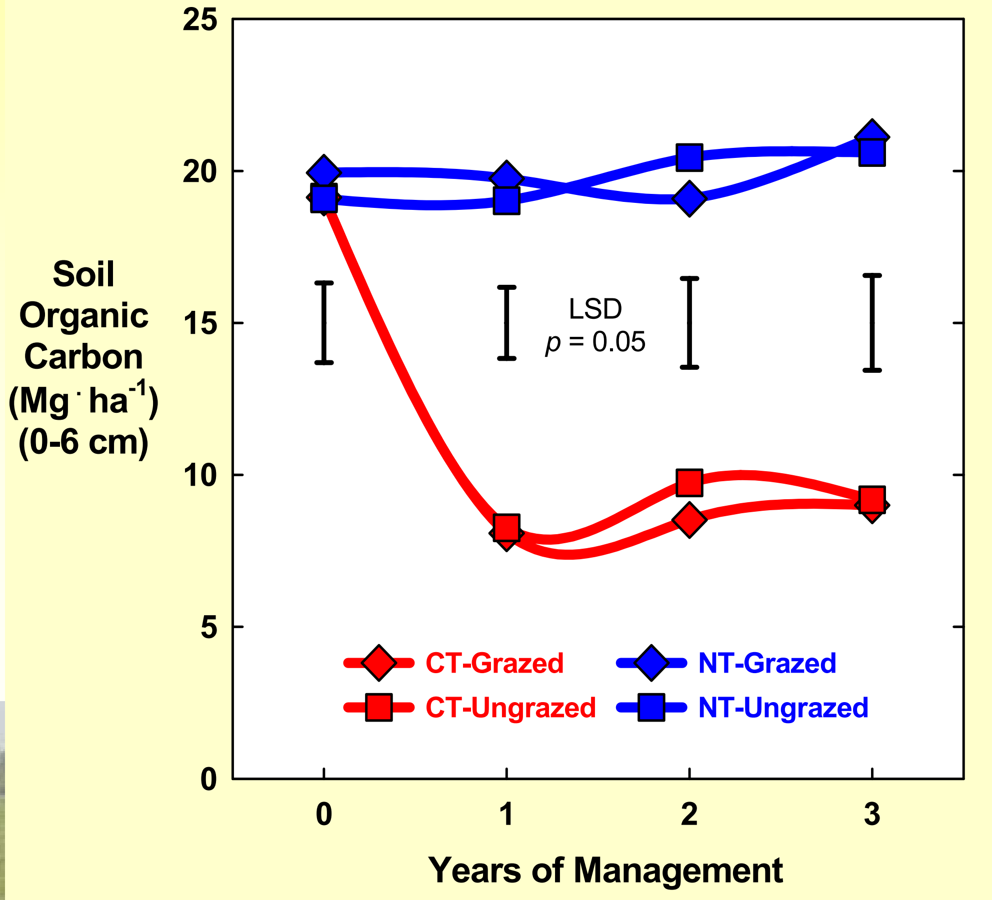


Franzluebbers et al. (2001) Soil Sci. Soc. Am. J. 65:834-841 and unpublished data

Cropland-Grazingland Rotation

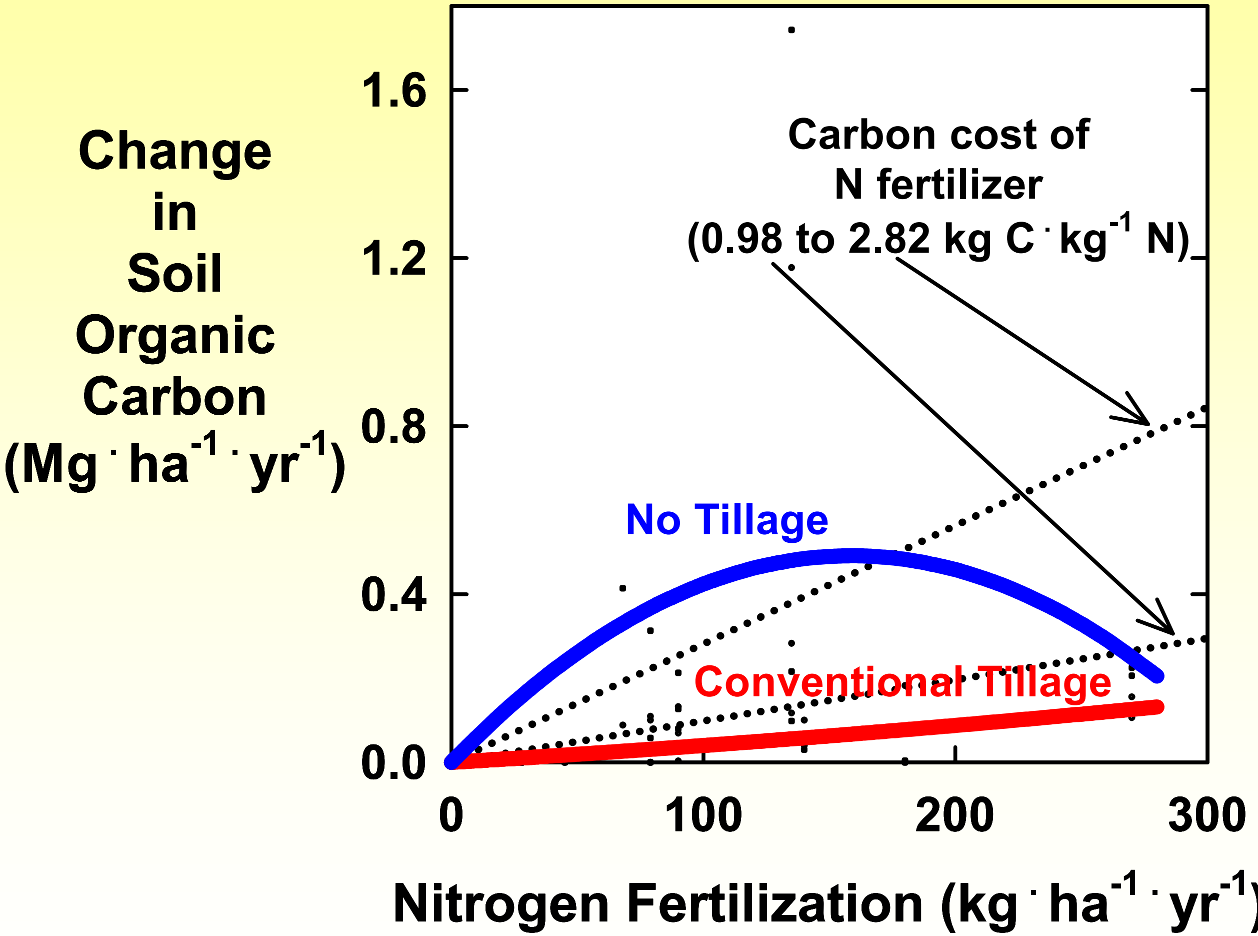
✓ Opportunities exist to capture more carbon from crop and grazing systems when the two systems are integrated:

- **Utilization of ligno-cellulosic plant materials by ruminants**
- **Manure deposition directly on land**
- **Weeds can be managed with management rather than chemicals**



Franzluebbers and Stuedemann (unpublished)

Optimal Fertilization



Therefore, soil carbon sequestration needs to be evaluated with a system-wide approach that includes all costs and benefits

For those of us working on greenhouse gas issues, this provides us with a formidable challenge

Franzluebbers (2005) Soil Tillage Res. 83:120-147

Summary and Conclusions

- ✓ Greenhouse gas concentrations in the atmosphere are increasing and the threat of global change requires our attention
- ✓ A diversity of agricultural management practices can be employed to sequester more carbon in plants and soil
  - Syntheses of available data are needed
  - Gaps in our knowledge need to be researched
- ✓ Strategies to sequester soil carbon will also likely restore degraded land and avoid further degradation